Part 5: RADIONUCLIDE-SPECIFIC PARAMETERS

Radionuclide-specific parameters required for calculating soil screening levels include an area correction factor (ACF) for the external radiation exposure pathway, and the soil-water partition coefficient for radionuclides (K_d). This part of the background document describes the collection and compilation of these parameters for the SSL radionuclides.

5.1   Area Correction Factor - ACF (unitless)

The risk model used for the external radiation exposure pathway in this guidance effectively assumes that an individual is exposed to a source geometry that is effectively an infinite slab. The concept of an "infinite slab" means that the thickness of the contaminated zone and its aerial extent are so large that it behaves as if it were infinite in its physical dimensions. In practice, soil contaminated to a depth greater than about 15 cm and with an aerial extent greater than about 1,000 m^2 (i.e., one-quarter acre) will create a radiation field approaching that of an infinite slab.

This infinite slab assumption has been used in the calculation of radionuclide slope factors presented in Section 2.1. For very small areas of contamination, this will result in overly conservative estimates of risk. For calculation of SSLs for a residential setting, an adjustment for source area is considered to be an important modification for Superfund sites. Thus, an area correction factor, ACF, has been added to the SSL calculation.

Table 5.1 provides recommended ACFs for radionuclides as a function of source area calculated using MicroShield V5.01.[1] Since the default source size is 0.5-acre (i.e., 2,000 m^2), the default ACF for SSL equations is set at 0.9. The calculations assume for a uniform layer of contamination 15 cm deep with a soil density of 1.6 g/cm^3. A single recommended value is considered suitable for all radionuclides over the range of source areas since EPA's analysis shows that ACFs vary little from one radionuclide to another. For other source areas, recommended ACFs are presented in Table 5.1.

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[1] Grove Engineering, Rockville, MD.

**Table 5.1 Recommended Area Correction
Factors as Function of Source Area**

Source Area (m²)	ACF
10,000	1.00
5,000	0.94
2,000	0.90
1,000	0.88
500	0.86
100	0.75
50	0.66
10	0.40

EPA's analysis of ACFs is found in Table 5.2, which provides examples of ACFs for several radionuclides as a function of source area calculated using MicroShield V5.01. The calculations assume for a uniform layer of contamination 15 cm deep with a soil density of 1.6 g/cm³. Strong gamma-ray emitters like ^{60}Co have relatively large slope factors for this pathway relative to the slope factors for weak photon emitters like ^{239}Pu. However, as noted in the table, ACFs vary little from one radionuclide to another over the range of source areas shown. Users that have one of the radionuclides in Table 5.2 as a contaminant at their site may use the radionuclide specific ACF that is appropriate for their source area rather than the value found in Table 5.1.

**Table 5.2 Area Correction Factors as Function of Source Area
for Selected Radionuclides Calculated Using MicroShield**

Source Area (m²)	^{231}Am	^{60}Co	^{137}Cs	^{239}Pu	^{226}Ra+D	^{232}Th	^{238}U+D
10,000	1.00	1.00	1.00	1.00	1.00	1.00	1.00
5,000	0.93	0.95	0.95	0.94	0.95	0.94	0.94
2,000	0.89	0.92	0.92	0.90	0.92	0.89	0.91
1,000	0.87	0.90	0.90	0.89	0.90	0.88	0.89
500	0.85	0.87	0.87	0.86	0.87	0.86	0.86
100	0.76	0.75	0.76	0.78	0.75	0.77	0.76
50	0.69	0.66	0.67	0.71	0.66	0.70	0.68
10	0.44	0.38	0.39	0.45	0.38	0.44	0.41

5.2 Soil-Water Distribution Coefficients (Kd) for Radionuclides

As with organic chemicals, development of SSLs for inorganics (including radionuclides) requires a soil-water partition coefficient or distribution cofficient (K_d) for each constituent. The soil- water distribution coefficient is typically defined in fate and contaminant transport calculation as the ratio of the contaminant

concentrations associated with the solid to the contaminant concentration in the surrounding aqueous solution when the system is at equilibrium (EPA 1999b). However, the simple relationship between soil organic carbon content and sorption observed for organic chemicals does not apply to inorganics (including radionuclides). The soil-water distribution coefficient (K_d) for inorganics (including radionuclides) is affected by numerous geochemical parameters and processes, including pH; sorption to clays, organic matter, iron oxides, and other soil constituents; oxidation/reduction conditions; major ion chemistry; and the chemical form of the radionuclide. The number of significant influencing parameters, their variability in the field, and differences in experimental methods result in as much as seven orders of magnitude variability in measured metal K_d values reported in the literature (see Table 43 in the Soil Screening Guidance: Technical Background Document (EPA 1996b)). This variability makes it much more difficult to derive generic K_d values for metals (including radionuclides) than for organics. Therefore, it is recommended that K_d values be measured for site-specific conditions. If the K_d is not measured site-specifically, then a conservative Kd should be used in calculating SSLs.

Tables 5.3 in the TBD (also C.2a in the User Guide) and C.2b in the User Guide list the default K_d values for each element. Table 5.2 is derived from the EPA Office of Radiation and Indoor Air's 1999 final document *Understanding Variation In Partition Coefficient, K_d, Values, Volume 1: The K_d Model of Measurement, and Application of Chemical Reaction Codes, & Volume 2: Review of Geochemistry and Available K_d Values for Cadmium, Cesium, Chromium, Lead , Plutonium, Radon, Strontium, Thorium, Tritium, and Uranium*. This document is intended to provide technical information to EPA and/or DOE transport modelers on the key geochemical processes affecting contaminant transport through soil and sediments. Particular attention is directed at providing an understanding of: 1) the use of distribution coefficients, 2) the difference between the original thermodynamic K_d parameter derived from the ion-exchange literature and its "empiricized" use in contaminant transport codes, 3) the explicit and implicit assumptions underlying the use of the K_d paramter in contaminant transport codes, and 4) methods for site-specific measurements.

When estimating migration of contaminants from soil to groundwater for a contaminant which is not represented with a default K_d value in either Table 5.3 or Tables C.2a and C.2b in the User Guide, site decision-makers should measure a site-specific K_d. Site decision-makers also may develop site-specific K_ds to more accurately estimate contaminant migration rather than using the default values in Tables 5.4 to 5.9 or either Tables C.2a or C.2b or in the User Guide.

The elements chosen for study in EPA (1999b) include the following: chromium, cadmium, cesium, lead, plutonium, radon, strontium, thorium, tritium, and uranium. The selection of these contaminants by EPA staff was based on two criteria. First, the elements had to be one of high priority to the site remediation or risk assessment activities of EPA and/or DOE (EPA 1993). Second, six nonexclusive categories were developed based on chemical behavior:

        1)   Cations - cadmium, cesium, plutonium, strontium, thorium, and uranium;
        2)   Anions - chromium (as CrO_4^{2-});
        3)   Radionuclides - cesium, plutonium, radon, strontium, thorium, tritium, and uranium;
        4)   Conservatively Transported Contaminants - tritium and radon;
        5)   Nonconservatively Transported Contaminants - other than tritium and radon; and
        6)   Redox Sensitive Elements - chromium, plutonium, and uranium.

By categorizing the contaminants in this manner, general geochemical behaviors of one contaminant may

be extrapolated by analogy to other contaminants in the same category. For example, contaminants present primarily in anionic form, such as Cr(VI), tend to adsorb to a limited extent to geological materials (soil, rocks, and geological deposits, hence forth simply referred to as soils). Thus, one might generalize that other anions, such as nitrate, chloride, and U(VI)-anionic complexes, would also adsorb to a limited extent. Literature on the absorption of these three solutes shows no or very little adsorption. Volume 2, EPA (1999) identifies, when possible, minimum and maximum conservative K_d values for each contaminants as a function of key geochemical processes affecting sorption. The tables that follows reflect this conservatism in using the lower bounding K_d values for these contaminants. Site specific measurements of K_d values should be used in determining SSLs. If K_d is not measured site-specifically, then conservative K_d values should be used from the following tables when calculating SSLs.

Table 5.3 Default K_d Values for Selected Elements, based on EPA (1999b).

Element	K_d value* (ml/g)	Element	K_d value (ml/g)
Cs	10	Sr	1
H	0	Th	20
Pu	5	U	0.4
Rn	0		

*Note: K_d values were given of units in ml/g inEPA (1999b). The units in other parts of this TBD are given in L/kg. However, these are equivalent units, that is: 1 ml/g = 1 L/kg

The K_d values in Table 5.3 reflect the most conservative values provided for each element in EPA (1999). Each of these values are based on a chemical mechanism that was considered to provide the most conservative K_d value for that element. Users that have measured pH values at their site that differ from the range given in this report, may want to consult Tables 5.4 to 5.9 for alternative K_ds that are still conservative.

Table 5.4 shows the estimated conservative K_d values for cesium based on cation exchange capacity (CEC) (in meg/100 g) or clay content (in wt.%). This table is for systems containing low concentrations of mica-like minerals (i.e., <5% of the clay-size fraction). This table pertains to systems consisting of natural soils (as opposed to pure mineral phases), low ionic strength (<0.1 M), low humic material concentrations (<5 mg/l), no organic chelates (such as EDTA), and oxidizing conditions.

Table 5.4 K_d values for cesium as a function of cation exchange capacity or clay content low mica content soils

CEC (meg/100 g) / Clay Content (wt.%)	<3 / <4	3 - 10 / 4 - 20	10 - 50 / 20 - 60
K_d value (ml/g)	10	30	80

Source: EPA (1999b)

Table 5.5 also shows the estimated conservative K_d values for cesium based on CEC or clay content, but for systems containing high concentrations of mica-like minerals (i.e., >5% of the clay-size fraction).

Table 5.5 K_d values for cesium as a function of cation exchange capacity or clay content for high mica content soils

CEC (meg/100 g) / Clay Content (wt.%)	<3 / <4	3 - 10 / 4 - 20	10 - 50 / 20 - 60
K_d value (ml/g)	30	70	210

Source: EPA (1999b)

Table 5.6 shows the EPA (1999b) look-up-table for plutonium, which is a function of clay content (in wt.%) and dissolved carbonate (in meq/l).

Table 5.6 K_d values for plutonium as a function of soluble carbonate and soil clay values

Clay Content (wt.%)	0 - 30			31 - 50			51 - 70		
Soluble Carbonate (meg/100 g)	0.1 - 2	3 - 4	5 - 6	0.1 - 2	3 - 4	5 - 6	0.1 - 2	3 - 4	5 - 6
K_d value (ml/g)	5	80	130	380	1,440	2,010	620	1,860	2,440

Source: EPA (1999b)

The look-up-table for strontium, Table 5.7, requires knowledge of the CEC (or clay content) and pH of the system in order to select the appropriate conservative strontium K_d value. This table pertains to systems consisting of natural soils (as opposed to pure mineral phases), low ionic strength (<0.1 M), low humic material concentrations (<5 mg/l), no organic chelates (such as EDTA), and oxidizing conditions.

Table 5.7 K_d values for strontium as a function of CEC, clay content, and pH

CEC (meg/100 g)	<3			3 - 10			10 - 50		
Clay Content (wt.%)	<4			4 - 20			20 - 60		
pH	<5	5 - 8	8 - 10	<5	5 - 8	8 - 10	<5	5 - 8	8 - 10
K_d value (ml/g)	1	2	3	10	15	20	100	200	300

Source:) EPA (1999b)

The look-up-table for thorium, Table 5.8, is based on plume thorium concentrations and pH. This table pertains to systems consisting of natural soils (as opposed to pure mineral phases), low ionic strength (<0.1 M), low humic material concentrations (<5 mg/l), no organic chelates (such as EDTA), and oxidizing conditions.

Table 5.8 K_d values for thorium as a function of pH and dissolved thorium concentrations

pH	3 - 5		5 - 8		8 - 10	
Dissolved Th, *M*	$<10^{-2.6}$	$>10^{-2.6}$	$<10^{-2.6}$	$>10^{-2.6}$	$<10^{-2.6}$	$>10^{-2.6}$
K_d value (ml/g)	62	300,000	1,700	300,000	20	300,000

Source: EPA (1999b)

Table 5.9 shows the EPA (1999b) look-up-table for uranium, which is a function of clay content (in wt.%) and dissolved carbonate (in meq/l).

Table 5.9 K_d values for uranium as a function of pH

pH	3	4	5	6	7	8	9	10
K_d value (ml/g)	<1	0.4	25	100	63	0.4	<1	<1

Source: EPA (1999b)